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RESEARCH MEMORANDUM

A STUDY BY MEANS OF A DYNAMIC-MODEL INVESTIGATION OF THE USE OF CANARD SURFACES AS AN AID IN RECOVERING FROM SPINS AND AS A MEANS FOR PREVENTING DIRECTIONAL DIVERGENCE NEAR THE STALL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A STUDY BY MEANS OF A DYNAMIC-MODEL INVESTIGATION OF THE USE OF CANARD SURFACES AS AN AID IN RECOVERING FROM SPINS AND AS A MEANS FOR PREVENTING DIRECTIONAL DIVERGENCE NEAR THE STALL

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SUMMARY

Mass loadings and configurations of contemporary fighter airplanes are such that effective ailerons are generally required for recovery from spins. Eliminating ailerons on some designs in favor of spoilers, or movement of ailerons inboard, may necessitate modifications or additions to the airplane configuration to provide satisfactory spin recoveries. A modification which is presented is the incorporation of small canard surfaces into the design. Results of tests in the Langley 20-foot free-spinning tunnel of dynamic models of two sweptback-wing fighter airplanes showed that canard surfaces were very effective in aiding termination of spins of these models.

Free-flight tests were also conducted on one of the models on a catapulting apparatus using canard surfaces as a means for preventing a directional divergence near the stall and possible subsequent spin entry. The results of these tests indicated that suitably placed canard surfaces were effective in preventing the directional divergence on the model.

INTRODUCTION

Because of the extreme fuselage-heavy loadings encountered in current designs, a specific control technique is generally required for recovery from the spin; namely, movement of ailerons with the spin (stick right in a right spin). (See ref. 1.) Combinations of high inertias and high angular velocities encountered in spins and the current practice of moving ailerons inboard or substituting spoilers for them, however, are giving rise to a situation in which lateral controls may not be sufficiently effective for spin recovery. This paper proposes the possible use of canard surfaces as an aid in the termination of the spin rotation. Results of model tests of two contemporary fighters conducted in the Langley 20-foot free-spinning tunnel with and without such canard surfaces incorporated into the design are presented herein.

Another problem being encountered in current designs is a directional divergence near the stall, because of loss in directional stability, and a subsequent spin entry. Dynamic-model test results are presented herein for one of the designs used in the spin investigation with canard surfaces installed as a means for preventing the divergence. This portion of the investigation was conducted by utilizing the catapulting apparatus described in reference 2. In this connection, some static force-test data obtained are also presented showing the effect of canards on yawing moment due to sideslip.

SYMBOLS

b	wing span, ft
S	wing area, sq ft
$\bar{c}$	mean aerodynamic chord, ft
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X,I_Y,I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slugs/cu ft

μ relative density of airplane, $m/\rho Sb$

γ glide-path angle, deg

α angle of attack, or, for the spin tests, the angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

α_{trim} trim angle of attack, deg

ϕ angle between span axis and horizontal, deg

β angle of sideslip, deg

V full-scale true rate of descent in spins or resultant velocity, for catapult tests, ft/sec

Ω full-scale angular velocity about spin axis, rps

i_t horizontal-tail incidence, positive with leading edge up, deg

δ_a aileron deflection, deg

δ_r rudder deflection, deg

V_s stalling speed, ft/sec

q angular pitching velocity about Y body axis, positive when nose up, radians/sec

p angular rolling velocity about X body axis, positive when in the same sense as the spin, radians/sec

r yawing velocity about Z axis, positive when in the same sense as the spin, radians/sec

M_Z yawing moment about Z body axis, ft-lb

C_n yawing-moment coefficient about Z body axis, $\frac{M_Z}{qSb}$

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$ per degree

F.S. fuselage station

W.L. water line

M_Y aerodynamic pitching moment, negative nose down, ft-lb

R spin radius, ft

N_{Re} Reynolds number

APPARATUS AND METHODS

Model

The two models used for the dynamic-model investigations were constructed of plastic impregnated fiber glass. The models are considered representative of current swept-wing fighters, model 1 being considered a 1/25-scale model and model 2 a 1/24-scale model. Photographs of models 1 and 2 are shown as figures 1 and 2, respectively. Model 1 is equipped with inboard ailerons and model 2 is equipped with slotted spoiler ailerons. The various canard surfaces investigated for the spin investigation are shown in tables I and II, and various positions of canard 6 investigated during the catapult tests are shown in figure 3.

A model was used for the force tests which was similar to model 1 except that it was an 0.085-scale model. Canard 7 shown in table I was investigated on this model, except that its vertical position corresponded to that shown in figure 3 for the position just below the fuselage reference line. On the 0.085-scale model this corresponded to 0.38 inch. (On the 1/25-scale model shown in fig. 3 this dimension is 0.18 inch below the fuselage reference line.)

The canard surfaces were generally curved to conform to the fuselage contours when in the retracted position except for canard surfaces 1 to 3 on model 1 (table I) which were flat-plate surfaces. The geometric characteristics of the models scaled up to airplane values are presented in table III.

Testing Techniques

Spin tests.- The operation of the Langley 20-foot free-spinning tunnel is generally similar to that described in reference 3 for the Langley 15-foot free-spinning tunnel except that the model-launching technique is different. With the controls set in the desired position, a model is launched by hand with rotation into the vertically rising airstream. After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The tests are photographed with a motion-picture camera. The spin data obtained from these tests are then converted to corresponding full-scale values by methods described in reference 3.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for the normal spinning-control configuration (elevator full up, lateral controls neutral, and rudder full with the spin) and for various other lateral control and elevator combinations including neutral and maximum settings of the surfaces. Recovery is generally attempted by rapid full reversal of the rudder, by rapid full reversal of both rudder and elevator, or by rapid full reversal of the rudder simultaneously with moving ailerons to full with the spin. The particular control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model (refs. 1 and 4). Tests are also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning, and the results of these tests are considered those that might be obtained for the normal spin-control configuration. For these tests, the elevator is set at either full up or two-thirds of its full-up deflection, and the lateral controls are set at one-third of full deflection in the direction conducive to slower recoveries, which may be either against the spin (stick left in a right spin) or with the spin depending primarily on the mass characteristics of the particular model. Recovery is attempted by rapidly reversing the rudder from full with the spin to only two-thirds against the spin, by simultaneous rudder reversal to two-thirds against the spin and movement of the elevator to either neutral or two-thirds down, or by simultaneous rudder reversal to two-thirds against the spin and stick movement to two-thirds with the spin. Stick movement alone to two-thirds with the spin is also attempted in some instances when the rudder has no effectiveness. This control configuration and manipulation is referred to as the criterion spin, with the particular control settings and manipulation used being dependent on the mass and dimensional characteristics of the model.

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases. Recovery characteristics of a model are generally considered satisfactory if recovery attempted from the criterion spin in any of the manners previously described is accomplished within $2\frac{1}{4}$ turns. This value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

For recovery attempts in which a model strikes the safety net while it is still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net (as >3). A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. When a model recovers without control movement (rudder held with the spin), the results are recorded as "no spin." When the number of turns required for recovery is 10 or more, the result is recorded as ∞.

Catapult tests.- The technique employed for the catapult tests was generally similar to that indicated in reference 2 in that the model was launched inside a building from a height about 55 feet above the floor at a speed corresponding to approximately the stalling speed. A large net for retrieving purposes was hung from the wall opposite the launching apparatus. Motion-picture records of the flights were taken from the rear and from the side.

Some longitudinal trim tests conducted on model 1 in connection with the catapult tests were conducted in the 20-foot free-spinning tunnel with the model free to pivot about its center of gravity.

Precision

The results are believed to be true values given by the models within the following limits:

α, deg	± 1
ϕ, deg	± 1
V, percent	± 5
Ω, percent	± 2
Turns for recovery obtained from motion-picture records	$\pm 1/4$
Turns for recovery obtained visually	$\pm 1/2$

The preceding limits may be exceeded for certain spins in which it is difficult to control the model in the free-spinning tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight and mass distribution of models is believed to be within the following limits:

Weight, percent	± 1
Center-of-gravity location, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5

Controls are set with an accuracy of $\pm 1^{\circ}$.

Comparison between model and full-scale spin results in reference 5 indicated that model tests accurately predicted full-scale recovery characteristics approximately 90 percent of the time and that, for the remaining 10 percent of the time, the model results were of value in predicting some of the details of the full-scale spins, such as motions in the developed spin and proper recovery techniques. The airplanes generally spun at an angle of attack closer to 45° than did the corresponding models. The comparison presented in reference 5 also indicated that, generally, the airplanes spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding models, although the higher rate of descent was found to be generally associated with the smaller angle of attack regardless of whether it was for the model or the airplane.

Test Conditions

The loading conditions tested on the models are given in table IV. For the spin tests, model 1 was ballasted to obtain dynamic similarity to an airplane at an arbitrary altitude of 30,000 feet (ρ = 0.000889 slugs/cu ft); whereas model 2 was arbitrarily ballasted at an equivalent test altitude of 25,000 feet (ρ = 0.001065 slugs/cu ft). A magnetic remote-control mechanism was installed in each of the models to actuate the controls for the recovery attempts, and sufficient moments were exerted on the controls to move them fully and rapidly.

For the catapult tests, only model 1 was investigated. The model was launched from the catapult at an angle of attack of 20° and a glide-path angle of 15°, corresponding to conditions at the stall. These conditions were held fixed throughout the tests and only the horizontal tail incidence was varied. The stabilizer incidence required for trim at the stall was -10°. Because of catapult speed limitations and because of space limitations within the building used for the tests, the lightest weight condition obtainable on the model was used, but the center-of-gravity position was maintained essentially constant for the spin and catapult tests (table IV).

The force tests were conducted only on model 1 in the Langley 300 mph 7- by 10-foot tunnel. The tests were conducted for a range of sideslip angles and angles of attack, all controls were neutral, and the dynamic pressure q varied from 5 to 40 pounds per square foot.

For all tests the models were in the clean condition. The maximum control settings (measured perpendicular to the hinge lines) used for the investigation were

	Model 1	Model 2
Rudder, deg	6 right, 6 left	25 right, 25 left
Horizontal tail incidence, i_t, deg	-30, 10	-18, 5
Ailerons, deg	15 up, 15 down	-----
Slotted spoiler ailerons, deg	-----	55 up, 0

RESULTS AND DISCUSSION

Spin Tests

The results of the spin tests of the models without canards installed are presented in charts 1 and 2. Spin test results with canard surfaces installed are presented in tables I and II and in figure 4. In those instances where no data are presented in the charts for certain control configurations, either no tests were conducted or the data were not considered pertinent. The model data are presented in terms of full-scale airplane values and the data are arbitrarily presented in terms of right-hand spins.

Comparison of chart 1 with table I and with figure 4 illustrates the effect of extending the canard surfaces on the recovery characteristics of model 1. As can be seen in chart 1, without canard surfaces operative, recovery by aileron movement to with the spin (stick right in a right spin) was poor. (As previously indicated, recoveries requiring more than $2\frac{1}{4}$ turns are considered unsatisfactory.) Although not presented on chart 1, reversal of the rudder for recovery was ineffective. Table I shows that extension of canard surfaces from an initial position flush with the fuselage in conjunction with moving ailerons to with the spin could be very effective in terminating the spin. The recovery characteristics of this model are considered satisfactory with canard surfaces 2, 3, 5, and 6 installed. These surfaces varied in area from approximately 2.25 to 4.5 percent of the wing area, and might well serve as access doors when in the retracted position. The plots shown in figure 4 indicate that the most desirable canards from the standpoint of being of assistance in bringing about spin recovery should be positioned at a high, forward location on the fuselage. In addition, the information presented in figure 4 also indicates that large canard areas and small canard aspect ratios are desirable.

Results of tests for model 2 presented in chart 2 show that placing the spoilers used for lateral controls either full with or full against the spin did not appreciably alter the spin from that obtained with the spoilers neutral. Consequently, no recoveries were attempted by movement of the lateral controls on this model because such a control movement would be expected to have no effect. Recoveries by rudder reversal or by rudder and horizontal-tail reversal were similar for all lateral-control settings and were either good or poor, apparently depending upon the phase of the model's oscillatory motion when the controls were moved for recovery. When canard surfaces varying from 1.65 percent to 6 percent of the wing area were extended and the rudder was simultaneously reversed against the spin for recovery, however, the recoveries were consistently good. (See table II.)

In order to explain the reason for the effectiveness of canards in damping the spin rotation, it is desirable to examine the yawing-moment and pitching-moment equations of the equations of motion (engine-gyroscopic terms and product of inertia terms not shown):

$$M_{Z_{aerodynamic}} + (I_X - I_Y)pq = I_Z\dot{r} \tag{1}$$

$$M_{Y_{aerodynamic}} + (I_Z - I_X)pr = I_Y\dot{q} \tag{2}$$

Experience has indicated that the most important moment affecting spin recovery is the yawing moment (eq. (1)). When a model or airplane is in spinning equilibrium, the aerodynamic and inertia moments are in balance, and recovery from the spin can be affected by disturbing this balance either by introducing a sufficient amount of aerodynamic yawing moment opposing the spin or by introducing a sufficient antispin inertia cross-couple yawing moment $(I_X - I_Y)pq$.

The primary effect of the canards appears to have been an aerodynamic damping in yaw provided when they were extended. This is brought out in figure 4(c) which shows that, when the canards were hinged high on the fuselage, the recoveries were considerably improved over those obtained on the basic model (chart 1); whereas when the canards were hinged low on the fuselage, the recoveries were essentially the same as those obtained on the basic model. The damping in yaw is brought about because the canards were placed near the forward end of the fuselage on the long-nosed models and because the spin axes for the two models were rearward of the nose and very close to the models' centers of gravity. In a spin, air then impinged on the forward portion of the fuselage from the direction in which the models were spinning (i.e., from the right side in a right spin) and below, giving rise to an air entrapping or damping effect when the canards were extended. (Effects similar to this have been observed in spins in the past when small horizontal surfaces were added ahead of and in the plane of the horizontal tail (ref. 6).) It would thus appear that, for canard surfaces to be most effective in spins, the spin axis when canards are retracted would have to be near the center of gravity. If the spin axis should be close to the nose when canards are retracted, the effectiveness of extending the canards may be greatly reduced. It should be noted, however, that when flat spins are obtained, the spin axis will generally be close to the center of gravity (radius small) unless the aerodynamic nose-down pitching moment is unusually low at spin attitudes (R varies as $\cos^2\alpha/-M$). A low aerodynamic nose-down pitching moment could be obtained at spin attitudes if the horizontal tail was positioned in such a manner that a large instability in pitch occurred at high angles of attack, or it could be obtained if the fuselage nose length were unusually large. For steep spins, the spin axis should be considerably ahead of the center of gravity and canards might have an adverse effect, but the normal controls of the airplane would be expected to be effective for such cases.

A secondary reason for the effectiveness of canards in aiding spin recovery is that the extended canards provide a nose-up aerodynamic pitching moment which gives rise to a positive increment in the angular pitching velocity q. This is obtained as is indicated in the pitching-moment equation (eq. (2)) and also because the inner wing will usually tilt in a downward direction in response to a nose-up pitching moment. This process influences the inertia cross-couple term in the yawing-moment equation $(I_X - I_Y)pq$ (eq. (1)), in such a manner as to provide an inertia yawing moment opposing the spin rotation. This is brought about because the models were heavily loaded along the fuselage so that I_Y greatly exceeded I_X and also by the fact that p is positive. Therefore, the resulting inertia cross-couple yawing term becomes negative or antispin. (See ref. 4.) The increment in nose-up aerodynamic pitching moment provided by the canards probably also had a retarding effect on the rate of spin rotation because of a change in the balance between the nose-down aerodynamic pitching moment and the nose-up inertia pitching moment which is maintained in a spin (eq. (2)). With a reduction in nose-down aerodynamic moment (brought about by extending canards), a smaller nose-up inertia moment or a lower rotational rate is required to maintain a balance.

Because of possible differences in the manner that models and full-scale airplanes may spin because of Reynolds number effects (ref. 5), the spin radius of the airplane and the scaled-up spin radius of the model may be somewhat different. In such a case, although the degree of effectiveness of canards on model and airplane may be somewhat different, the general effectiveness should be the same except for certain critical cases where the spin axis is near the canards. A correlation between model and full-scale airplane results on canard effectiveness in spins is desirable but is not available at present.

Catapult and Force Tests

The results of the catapult tests of model 1 are presented in figures 5 to 7. When the clean model was launched with lateral controls neutral and with a horizontal-tail incidence in excess of -10° (trailing edge up) the model pitched up, because the horizontal tail was set to trim the model at an angle of attack higher than the launching attitude, and then usually diverged in yaw. (See fig. 5.) Oftentimes the violent yawing divergence appeared to be the start of a spin, but because of space limitations the maximum change in heading that could be observed was only about three-fourths of a turn. A typical motion is shown in figure 6.

Tests were made with canard surface 6 (shown in table I) fixed at the various vertical locations shown in figure 3 in an attempt to improve the model's dynamic behavior at and beyond the stall. The results obtained with -20° incidence in the horizontal tail (fig. 5) indicate that placing the canards at the lower positions on the fuselage alleviated the viciousness of the observable motion but that the highest positioned canards had little effect. Test observations indicated that the best position tested was a location 0.18 inch (model dimension) below the fuselage reference line, and model results indicated that, for the many runs that were made, the model usually pitched up and then continued its glide with little or no yawing tendencies noted for the portion of the flight observable before the model hit the safety net. A typical motion with the canards attached in this position is shown as figure 7.

Additional catapult tests are presented in table V and force tests are presented in figures 8 to 10 for a range of Reynolds numbers. For these catapult tests and for the force tests, when the canard surfaces were installed they were placed at the vertical location found to be the most effective in preventing a divergence (canard 6 on table I located 0.18 inch below the reference line on the 1/25-scale model as indicated in fig. 3). The force-test data at the low Reynolds number, approximately 415,000, presented in figures 8 and 10 indicate that the clean model became unstable directionally near and beyond the stall angle $\alpha \approx 20^{\circ}$ and that installation of the canard surfaces had a somewhat beneficial effect on the directional stability for small sideslip angles at angles of attack above the stall. The catapult data presented in table V with the horizontal tail set for various trim angles above the stall indicate that, with canard surfaces installed, the portions of the flights that could be observed before the model struck the safety net were essentially straight; whereas in the clean condition, the model usually diverged directionally. The improvement in the model's behavior with canards installed is apparently attributable to the increase in directional stability at small sideslip angles as is indicated in figures 8 and 10. Comparison of the high and low Reynolds number force data presented in figures 8, 9, and 10 indicates that canards might be expected to have a beneficial effect in alleviating any tendencies to diverge directionally on the full-scale airplanes for stalled angles of attack up to somewhat greater than 30°. For angles of attack in excess of this, the canards would not be expected to have a beneficial effect at high Reynolds numbers.

It should be pointed out that only a limited model flight could be observed for the catapult tests because of space limitations within the building in which the tests were being performed. On this basis it is possible that the model with canard surfaces installed might eventually have diverged directionally if the flights had been longer. Sufficient evidence was obtained, however, to indicate that any tendency of the clean model to diverge directionally at a given angle of attack would at the least be delayed when properly positioned canards are installed.

Spin tests were not conducted on model 1 with the canards positioned in the location most effective for preventing the directional divergence. It would appear, however, that this position would not be the most desirable inasmuch as the optimum vertical positioning of canards for spin recovery was high on the fuselage. One compromise would be to position the canards near the fuselage reference line in order to alleviate the directional divergence tendencies and then to increase the canard chord (dimension along the longitudinal axis) for maximum effectiveness in spins. At the present time it appears that best positioning of canard surfaces for maximum effectiveness in alleviating a directional divergence will have to be evaluated for each specific design.

A film supplement showing the effect of canards during spin recovery and also in preventing directional divergence near the stall is available and can be obtained upon request from NACA Headquarters, Washington, D.C.

Effect of Jet-Engine Angular Momentum

The angular momentum of the jet engine was not simulated for either the spin or catapult tests. Based on information published in reference 7, it appears likely that the effects of canards for spin recovery and in preventing directional divergence could be influenced by the large angular momentum of current turbojet engines.

CONCLUDING REMARKS

Results of an experimental investigation utilizing two sweptback-wing dynamic models have shown that extending small canard surfaces from an initial flush-with-the-fuselage position to a horizontal position was very effective in aiding the termination of spins that could not be satisfactorily terminated by use of the existing control surfaces. A free-flight investigation of one of the models utilizing a catapulting apparatus also showed that suitably placed canard surfaces were effective in preventing a directional divergence near the stalled regime of flight. At the present time the positioning of canards for maximum effectiveness will have to be evaluated for each specific design.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 13, 1956.

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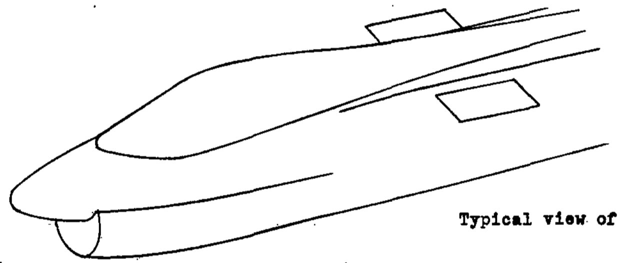
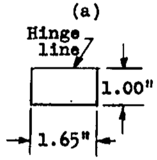
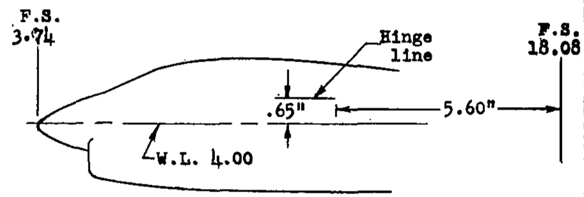
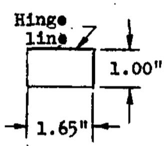
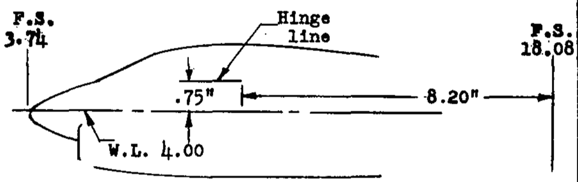
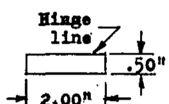
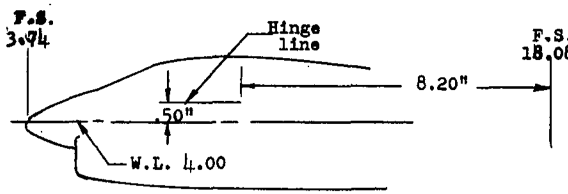
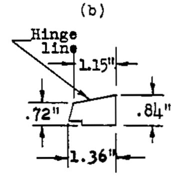
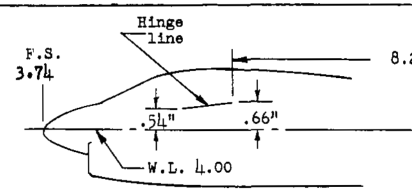
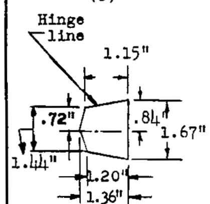
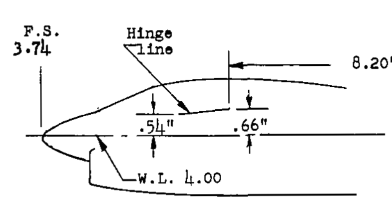
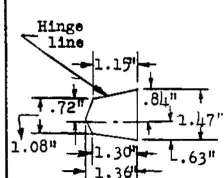
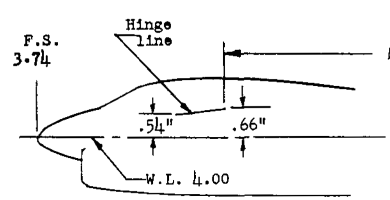
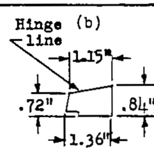
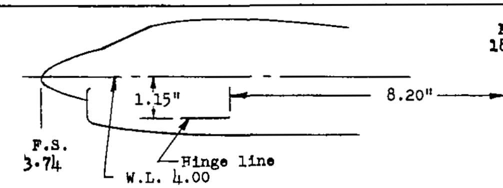
TABLE I.- LOCATION OF CANARD SURFACES ON MODEL 1 AND RECOVERY CHARACTERISTICS

[Recovery attempted by moving the ailerons to with the spin (stick right in a right spin) and simultaneously extending the canards; recovery attempted from rudder-full-with spins with the horizontal tail two-thirds up and ailerons one-third against the spin]

Canard	Outline of canard surface	Canard position on model	Area, sq in.	Final aileron throw with the spin for recovery, deg	Turns for recovery
		 Typical view of canards extended			
1	(a) 		3.30 (3.72 %S)	±15	5
2	(a) 		3.30 (3.72 %S)	±10	1, $1\frac{1}{2}$, 2
3	(a) 		2.00 (2.26 %S)	±10	1, $1\frac{1}{4}$

[a]Flat-plate surface.

TABLE I.- LOCATION OF CANARD SURFACES ON MODEL 1 AND RECOVERY CHARACTERISTICS - Concluded

Canard	Outline of canard surface	Canard position on model	Area, sq in.	Final aileron throw with the spin for recovery, deg	Turns for recovery
4	(b) 		1.87 (2.11 % S)	±10	$2\frac{3}{4}$, 3, 3
5	(b) 		3.94 (4.44 % S)	±10	$1\frac{3}{4}$, $1\frac{3}{4}$
6	(b) 		3.30 (3.72 % S)	±10	1, $1\frac{1}{2}$
7	(b) 		1.87 (2.11 % S)	±10	4, ∞

[b]Curved to fit contour of model.

TABLE II.- LOCATION OF CANARD SURFACES ON MODEL 2 AND RECOVERY CHARACTERISTICS

[Recovery attempted by reversing the rudder to full against the spin and sumultaneously extending the canards; recovery attempted from rudder-full-with spin with the elevator full up and the stick laterally neutral]

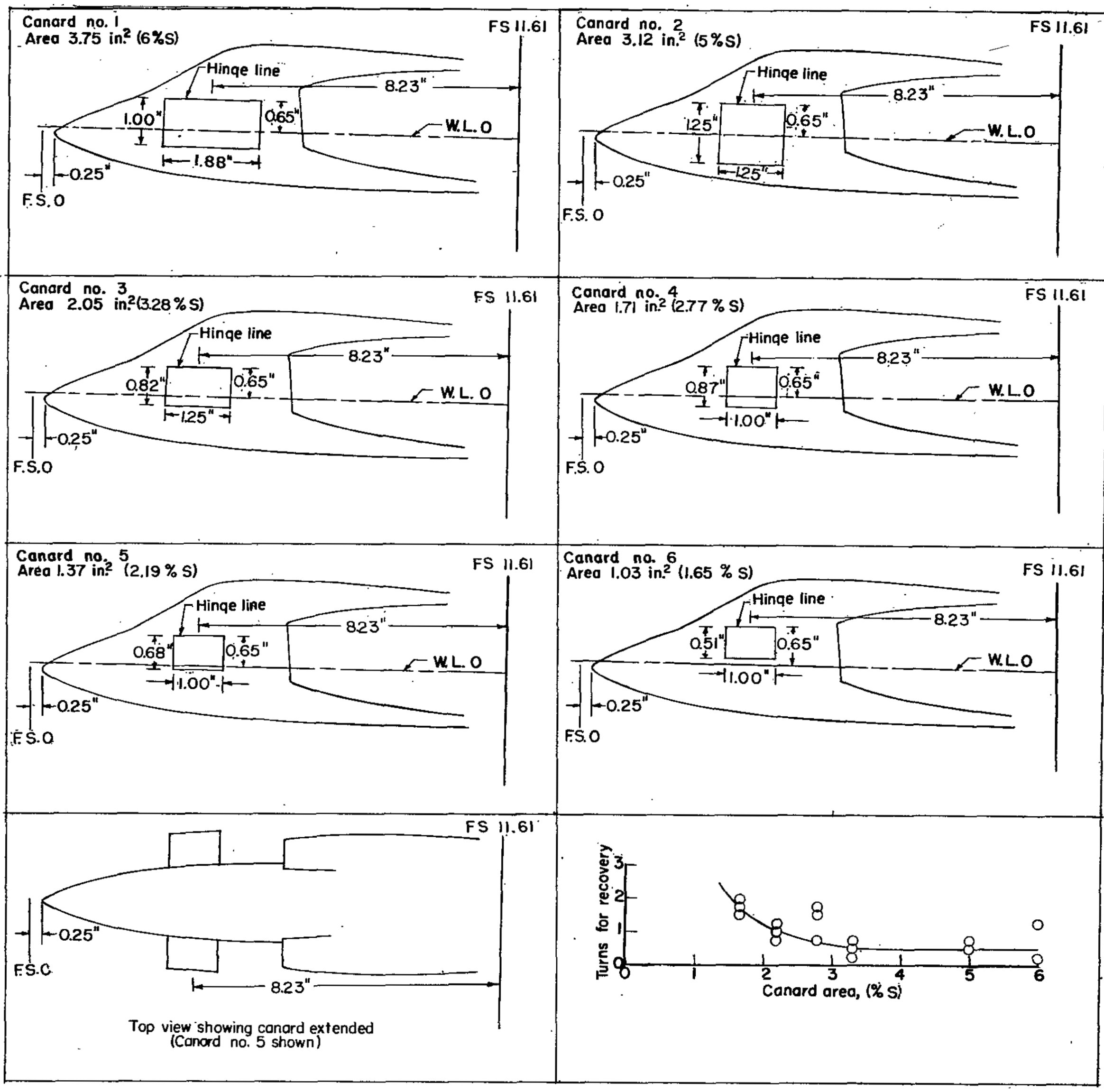


TABLE III.- FULL-SCALE DIMENSIONAL CHARACTERISTICS

[Model 1 is assumed to be 1/25 scale and model 2 is assumed to be 1/24 scale]

	Model 1	Model 2
Overall length, ft	54.23	40.83
Wing:		
Span, ft	35.67	31.63
Area (including fixed chord extension), sq ft	385.33	---
Area, sq ft	---	250
Mean aerodynamic chord, $\bar{c}$, in.	141.40	98.38
Leading edge of $\bar{c}$ rearward of leading edge of root chord, in.	92.68	66.07
Root chord, in.	202.00	126.48
Tip chord (including chord extension), in.	55.93	---
Tip chord	---	63.24
Aspect ratio (including chord extension)	3.30	---
Aspect ratio	---	4.00
Taper ratio (including chord extension)	0.28	---
Taper ratio	---	0.50
Sweepback at c/4, deg	42	35
Dihedral, deg	-5	-2.5
Incidence, deg	-1	0
NACA airfoil section:		
Root	65A006	Modified 65A006
Tip	65A005	Modified 65A004
Ailerons:		
Total area, sq ft	41.98	---
Span, percent b/2	40.38	---
Flaperons:		
Total area, sq ft	---	21.30
Span, percent b/2	---	61.73
Trailing edge, percent wing chord	---	84.00
Hinge, percent wing chord	---	70.00
Fence:		
Total area, sq ft	---	5.13
Location (from center of fuselage), in.	---	75.00
Horizontal tail:		
Area, sq ft	93.45	65.50
Span, ft	18.17	15.17
Sweepback at c/4, deg	45	35
Root chord, in.	108.05	74.21
Tip chord, in.	15.96	29.71
Aspect ratio	3.53	3.50
Taper ratio	0.15	0.40
Dihedral, deg	5.42	0
NACA airfoil section:		
Root	Modified 65A006	65A006
Tip	Modified 65A004	65A004
Vertical tail:		
Area (including dorsal), sq ft	82.36	---
Area (exposed), sq ft	---	34.8
Height (from fuselage reference line), ft	12.08	10.00
Rudder area (aft hinge line), sq ft	12.39	7.27
Sweepback at c/4, deg	45	35
NACA airfoil section:		
Root	Modified 65A006	0006
Tip	Modified 65A004	0006

TABLE IV.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE

LOADING TESTED ON MODELS 1 AND 2

[Model values are converted to full scale, and moments of inertia are given about the center of gravity]

Model	Weight, lb	Center-of-gravity location		Relative density, μ			Moments of inertia, slug-feet^2			Mass parameters		
		$x/\bar{c}$	$z/\bar{c}$	Sea level	Altitude, ft: 30,000	Altitude, ft: 25,000	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
1 (Spin loading)	23,565	0.339	0.030	22.40	59.90	--	11,587	83,367	88,614	-771×10^{-4}	-56×10^{-4}	827×10^{-4}
1 (Catapult loading)	17,241	0.336	-0.036	16.37	--	--	17,556	90,511	98,479	-1072×10^{-4}	-117×10^{-4}	1189×10^{-4}
2	14,284	0.299	0.026	23.60	--	52.69	6,373	31,477	35,531	-566×10^{-4}	-91×10^{-4}	657×10^{-4}

TABLE V.- CATAPULT TEST RESULTS OF MODEL 1

WITH AND WITHOUT CANARD SURFACES INSTALLED FOR DIFFERENT

TRIM SETTINGS OF THE LONGITUDINAL CONTROLS

[Model launched at $\alpha = 20^{\circ}$; center of gravity at approximately 33 percent $\bar{c}$ unless otherwise noted; launching velocity corresponded to the stalling speed; when canards were installed, canard 6 located 0.18 inch below the fuselage reference line was installed (fig. 3)]

i_t, deg	Trim angle, deg	Canards on or off	Model motion before hitting safety net
-10	Approx. 20	Off	Model will sometimes make as much as one-fourth turn
- 2	23	On	Straight
-15	27	Off	Model makes as much as one-half turn
- 6	26.5	On	Straight
-20	29	Off	Model starts to spin, three-fourths turn observed
-10	29	On	Usually straight, although at times may start to turn slightly
-30	37	Off	Model makes as much as three-fourths turn
-20	36	On	Straight
-30	[a]46.5	Off	Essentially straight
-30	45	On	Straight

[a]Center of gravity moved back to 42 percent $\bar{c}$ for this test.

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

WITHOUT CANARD SURFACES INSTALLED

[Recovery attempted by aileron movement to full-with the spin (stick right in a right spin), recovery attempted from, and steady-spin data presented for, rudder-full-with spins]

Model No. 1	Attitude Erect	Direction Right	Loading (see table IV)		
Slats Retracted	Flaps Retracted	Stabilizer Adjustable	Speed brakes Closed		

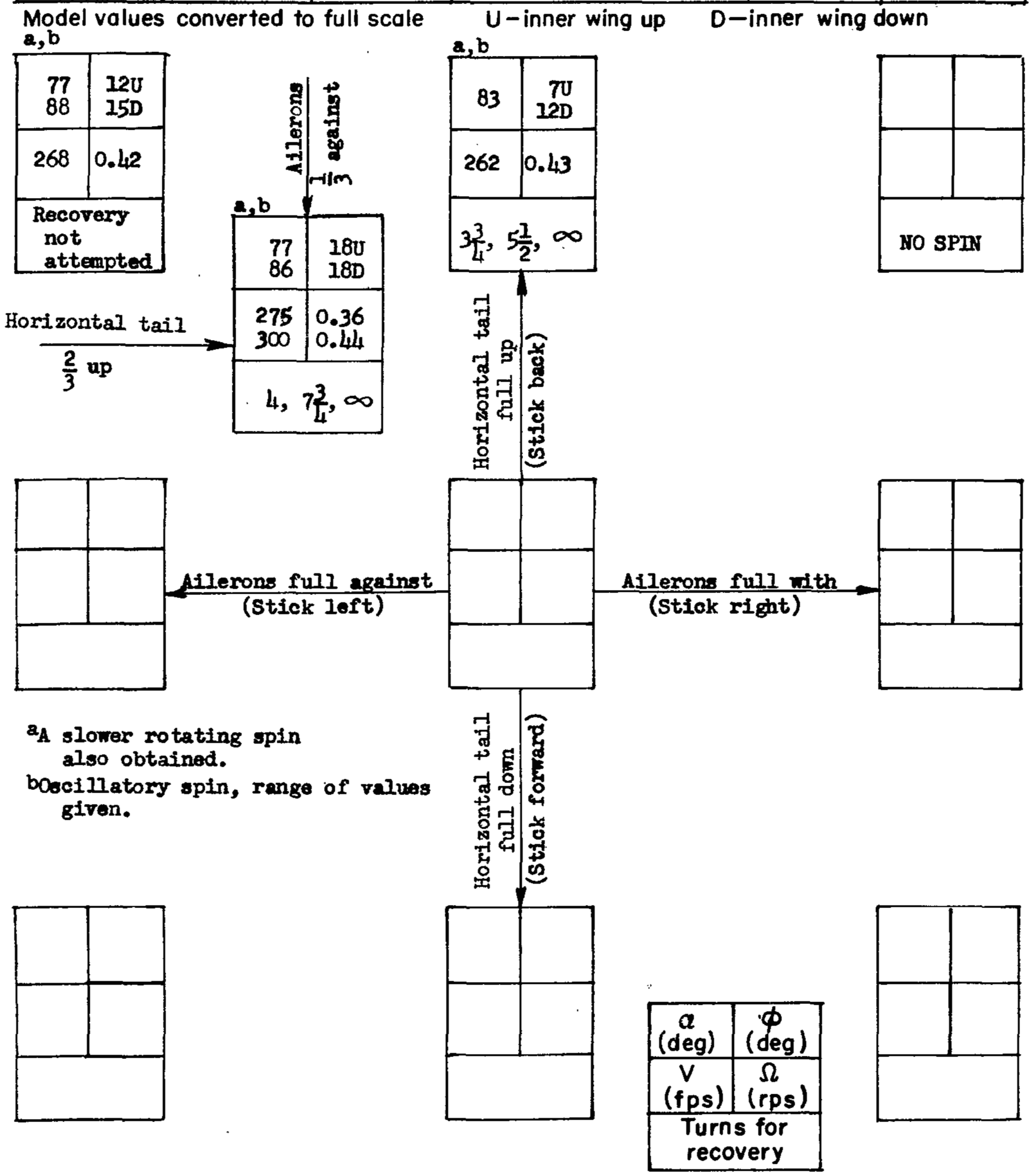


CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

WITHOUT CANARD SURFACES INSTALLED

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins]

Model No. 2	Attitude Erect	Direction Right	Loading (see table IV)		
Slats Retracted	Flaps Retracted	Stabilizer Adjustable	Speed brakes Closed		

Model values converted to full scale U—inner wing up D—inner wing down

Stick left (Flaperons full against), neutral, with stick back (Horizontal tail full up):

a 42 88	37U 25D
243	0.23
$1\frac{3}{4}$, 3, $>3\frac{1}{2}$	
b,c $3\frac{1}{2}$, b,c $3\frac{1}{2}$, b >4	

Stick centered, with stick back (Horizontal tail full up):

a -59 81	20U 32D	NO SPIN
236	0.24	
$4\frac{3}{4}$, $>4\frac{1}{2}$		
b,d $1\frac{3}{4}$, b 3, b $4\frac{1}{4}$		

Stick right (Flaperons full with), with stick back (Horizontal tail full up):

a 61 82	30U 23D
236	0.23
$1\frac{1}{2}$, 9, $>5\frac{1}{2}$	
b $2\frac{1}{2}$, b $2\frac{1}{2}$, b 5	

Horizontal tail full up (Stick back)

Flaperons full against (Stick left)

Flaperons full with (Stick right)

Horizontal tail full down (Stick forward)

(All remaining boxes of the chart are empty.)

[a]Oscillatory spin, range of values given.

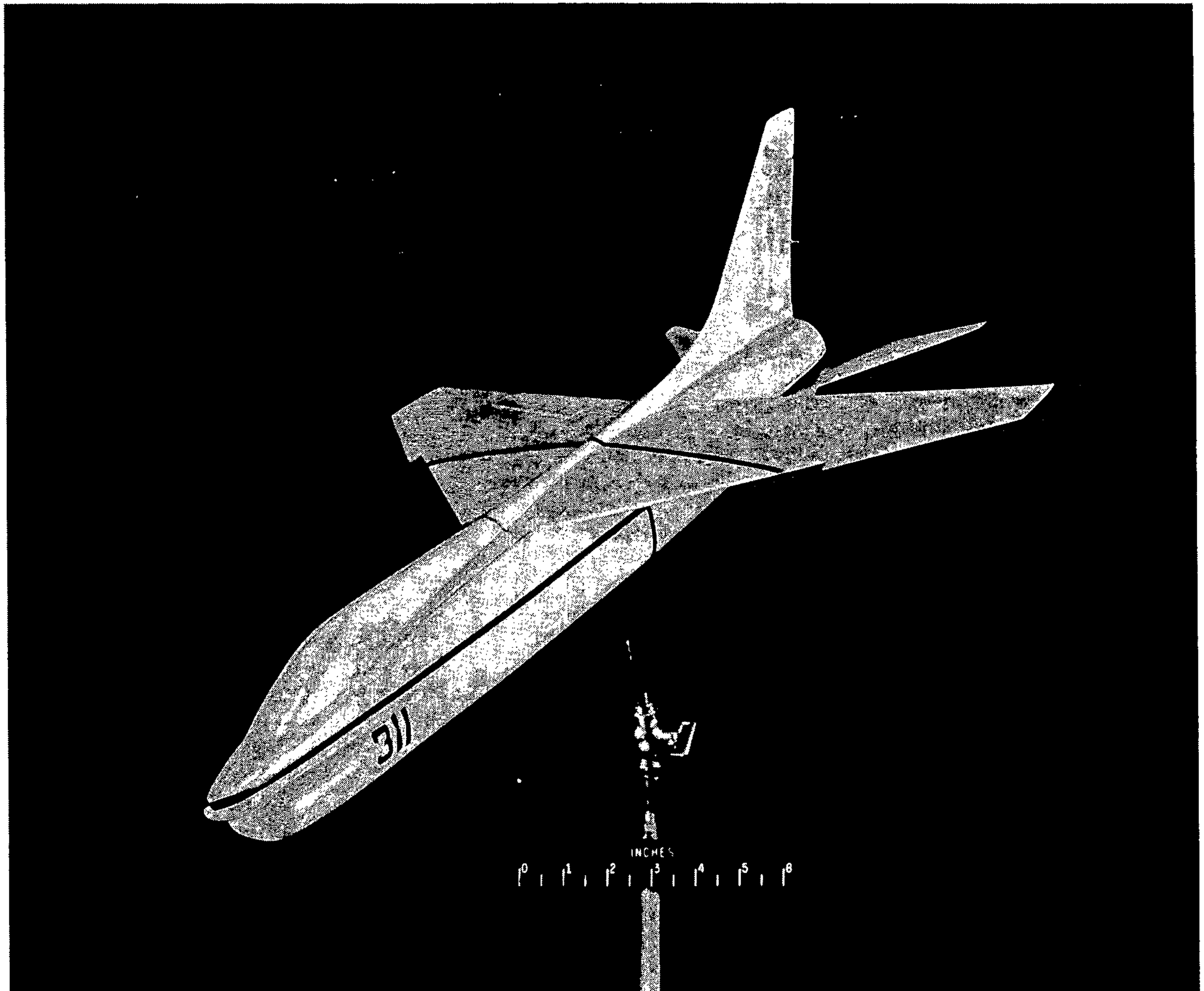
[b]Recovery attempted by simultaneously deflecting the rudder to full-against the spin and the horizontal tail to full down (stick forward).

[c]Recovers in an inverted glide.

[d]After recovery, model appears to start into an inverted spin.

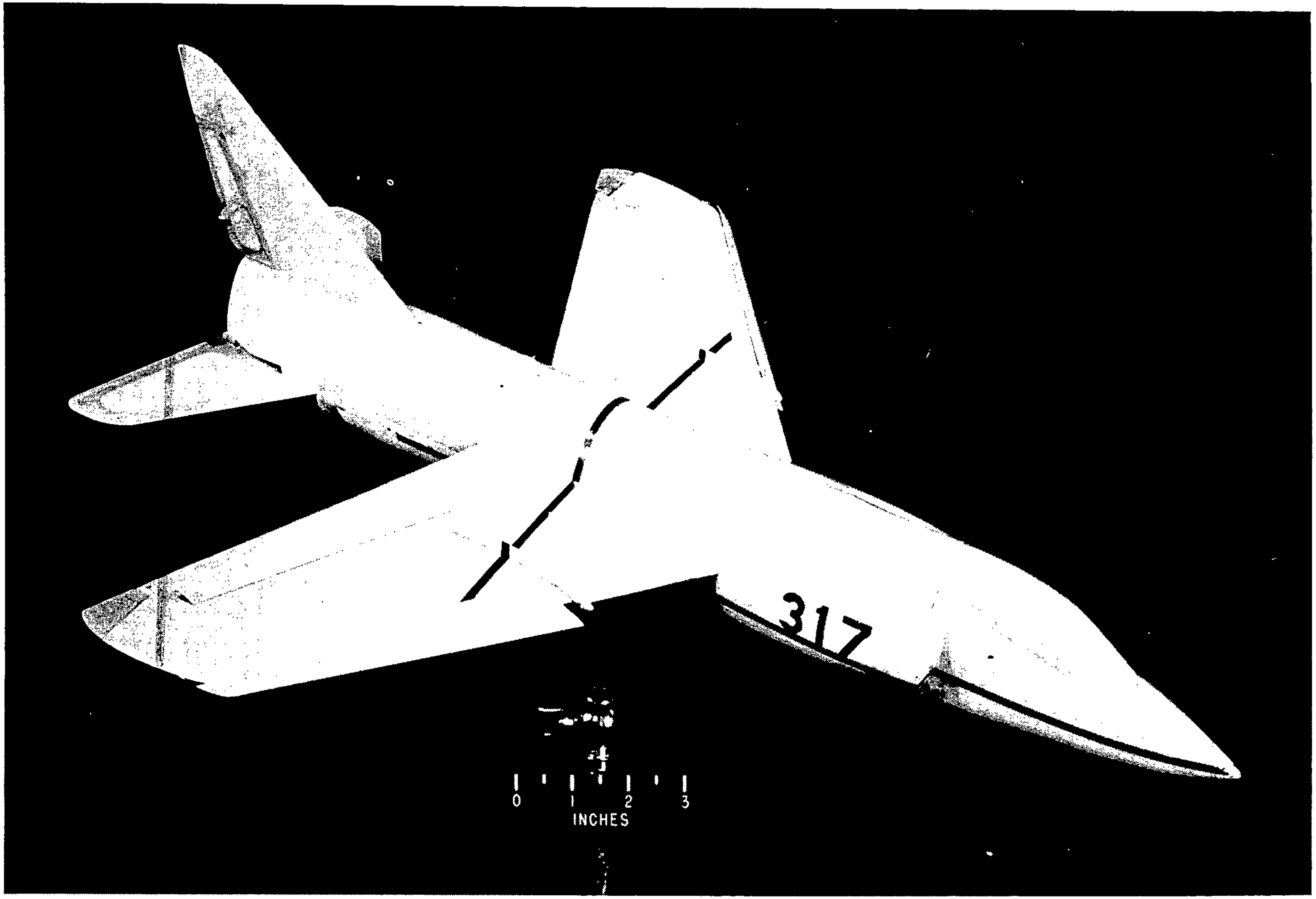
Key:

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	



L-83342

Figure 1.- Photograph of model 1.



L-84786

Figure 2.- Photograph of model 2 (model investigated with slats retracted).

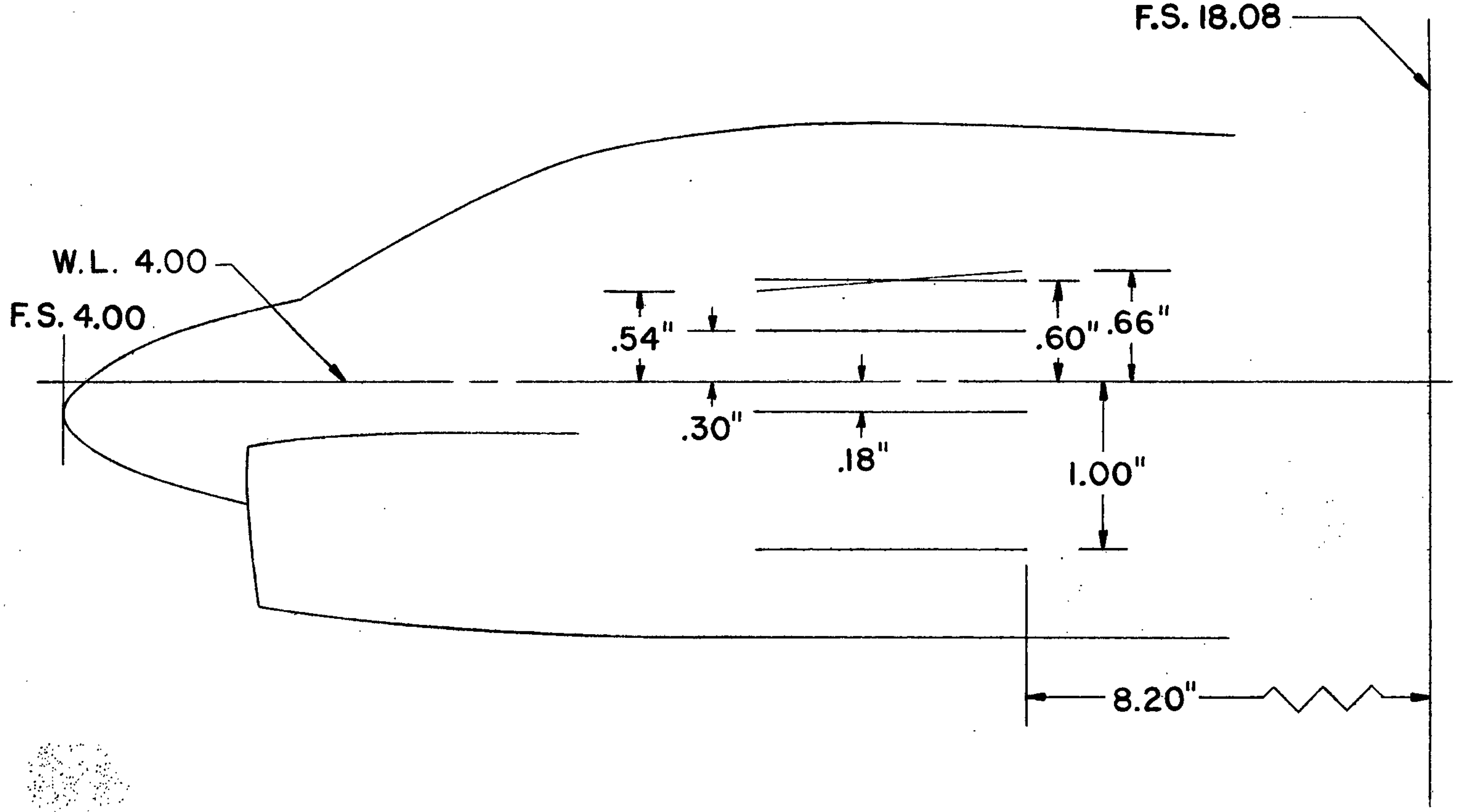
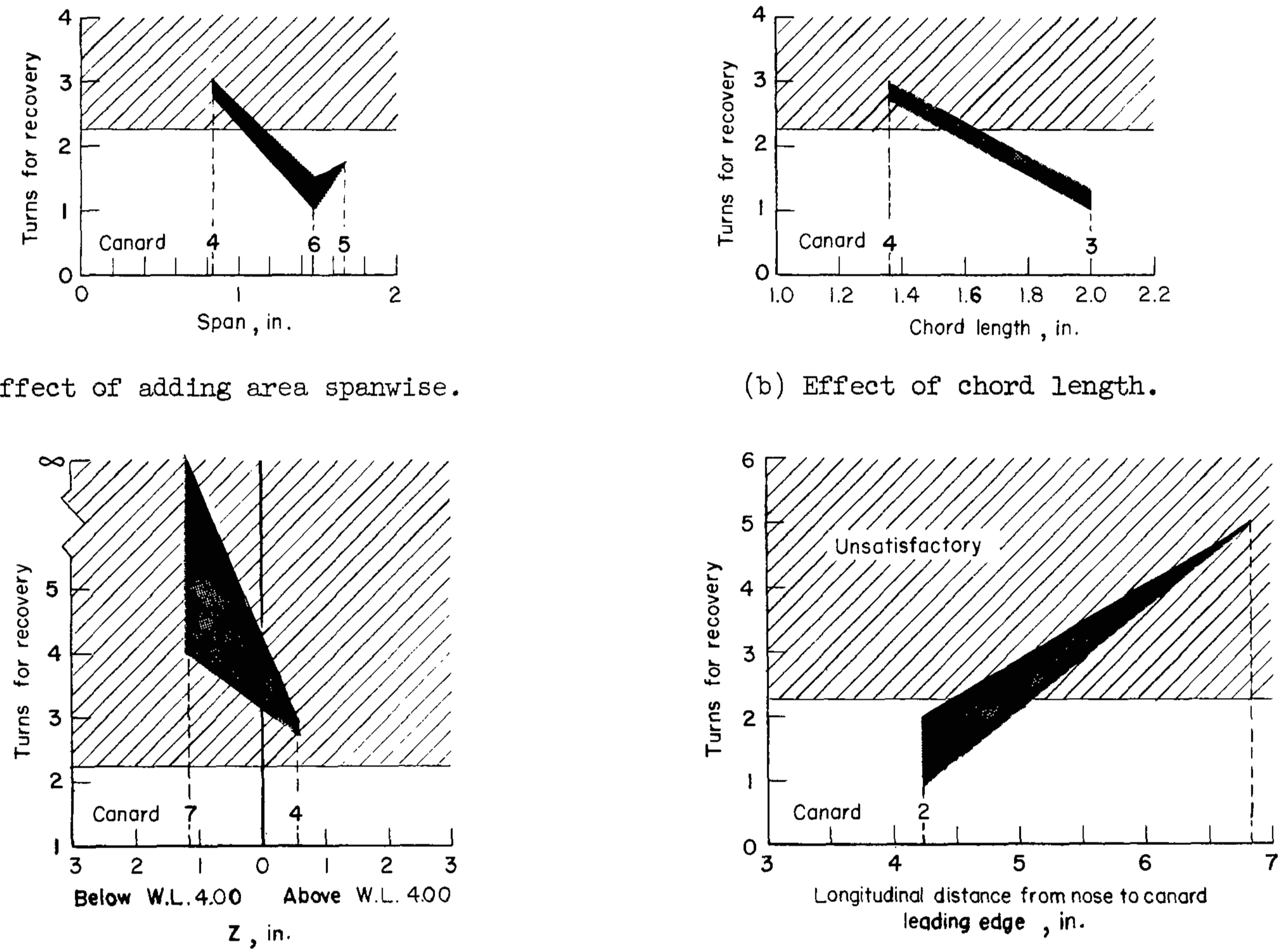


Figure 3.- Various vertical positions of canard 6 tested on model 1 during catapult tests.



(a) Effect of adding area spanwise.

(b) Effect of chord length.

(c) Effect of vertical position.

(d) Effect of horizontal position.

Figure 4.- Effect of canard variations on turns for recovery for model 1 as presented in table I. Range of recoveries obtained are indicated for each canard.

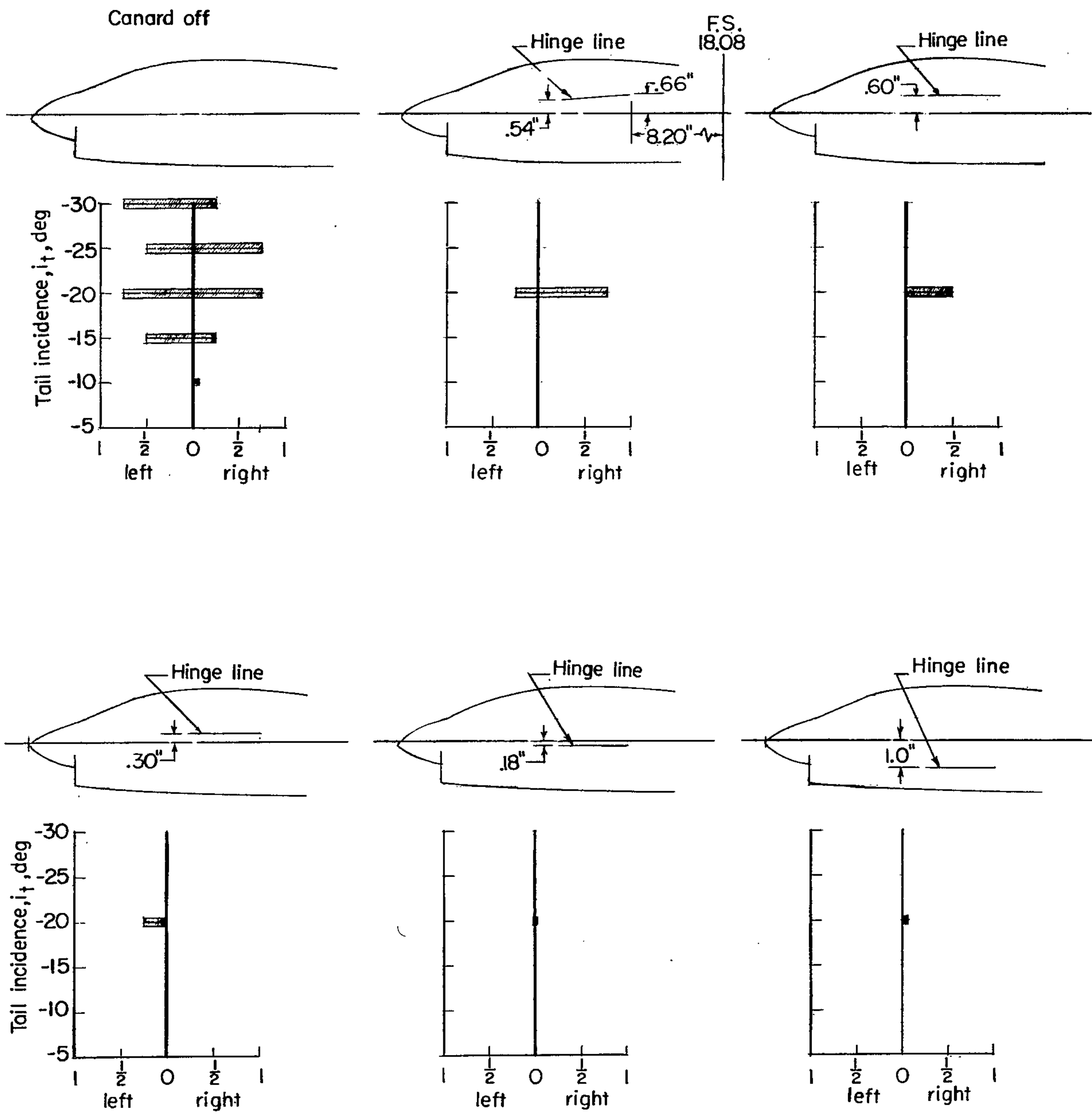
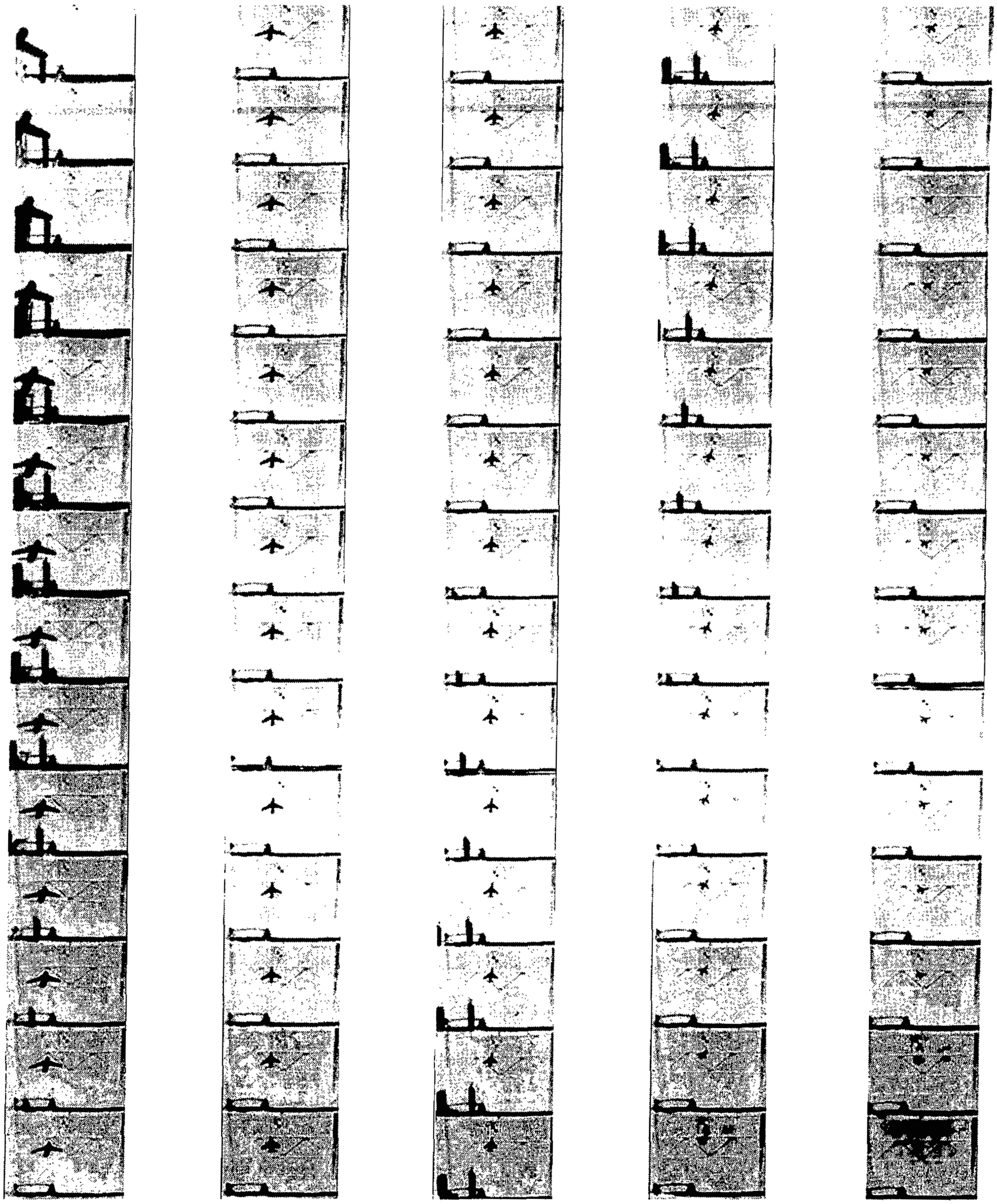


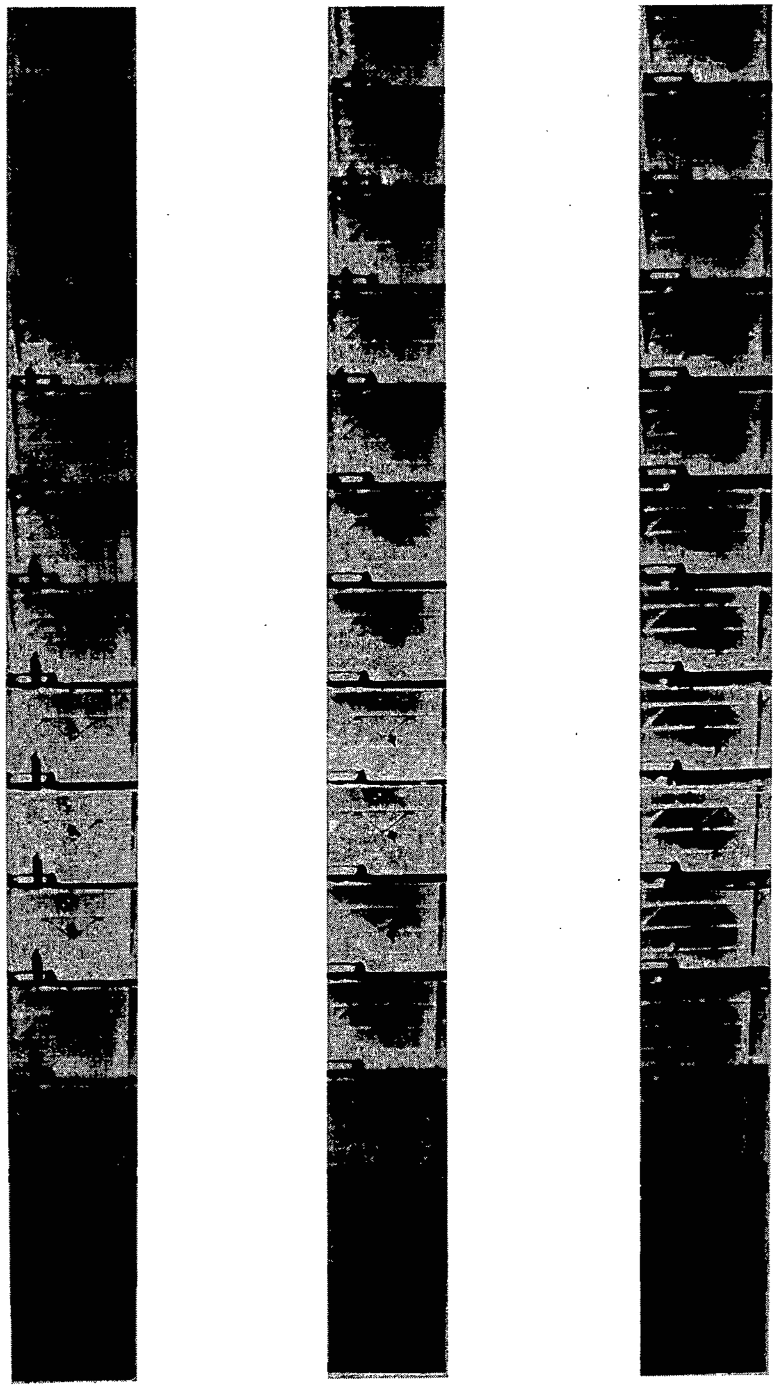
Figure 5.- Effect of canard positioning on preventing a directional divergence. Maximum observed heading change after various launchings, turns.



L-92426

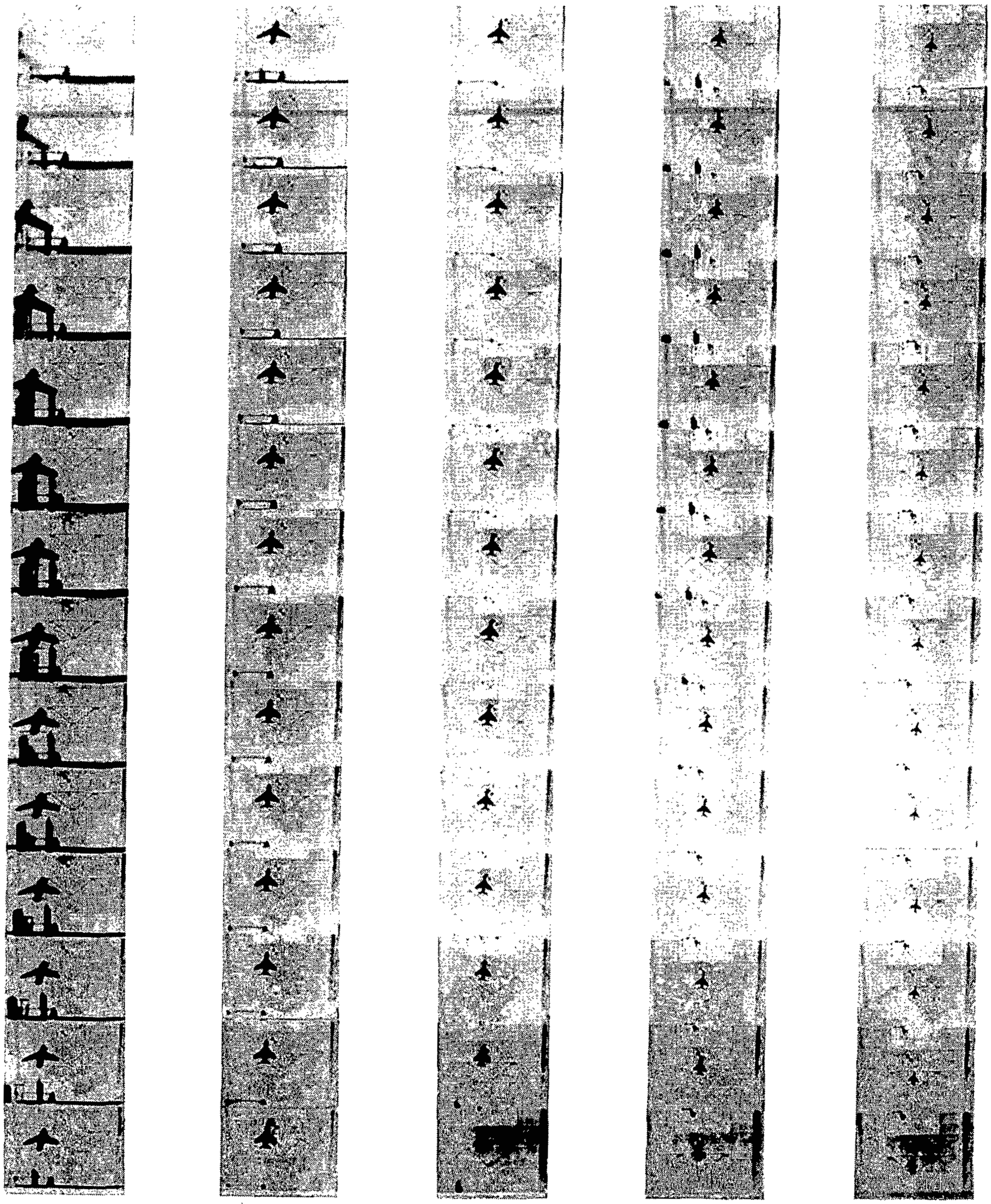
Figure 6.- Strip photograph of model 1 launched without canards installed.

[redacted]



L-92427

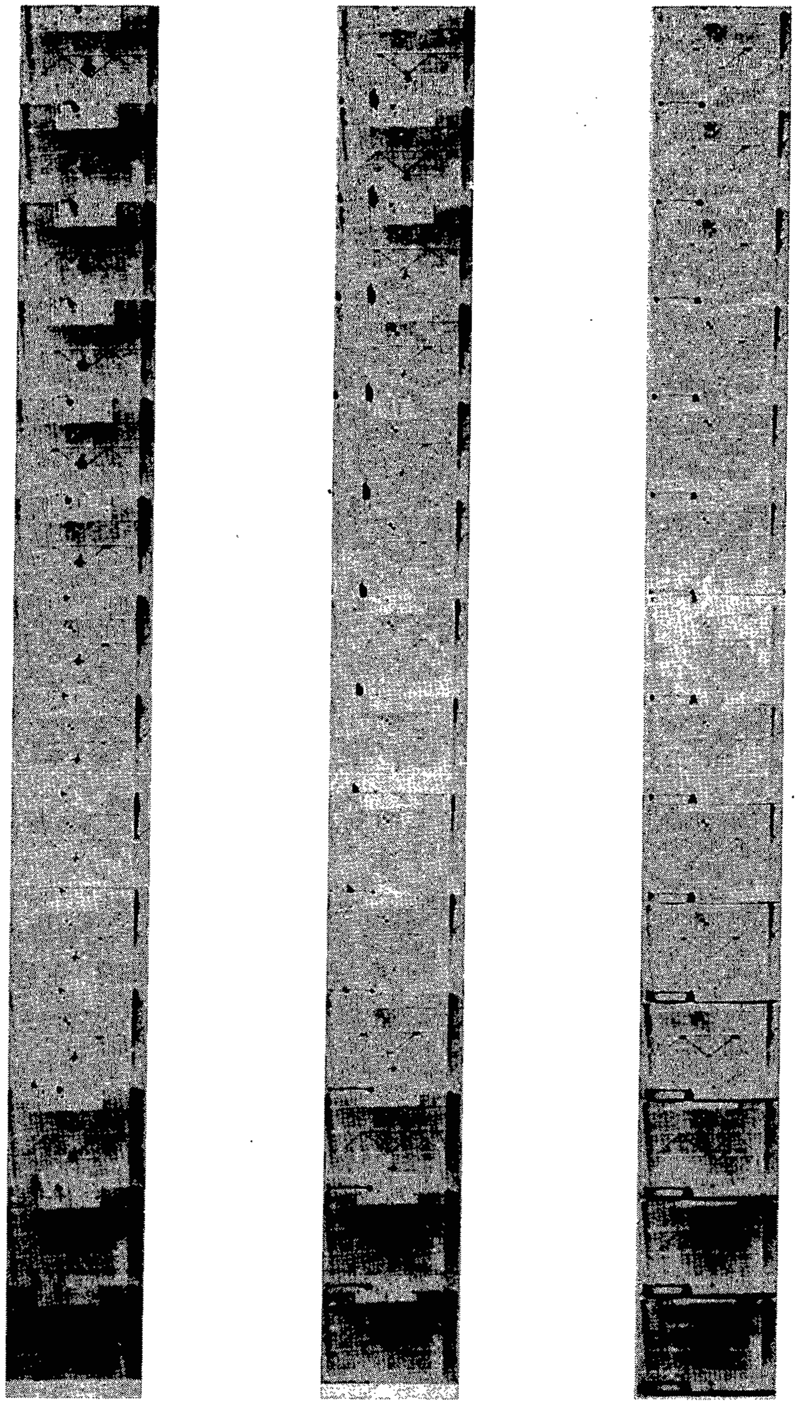
Figure 6.- Concluded.



L-92428

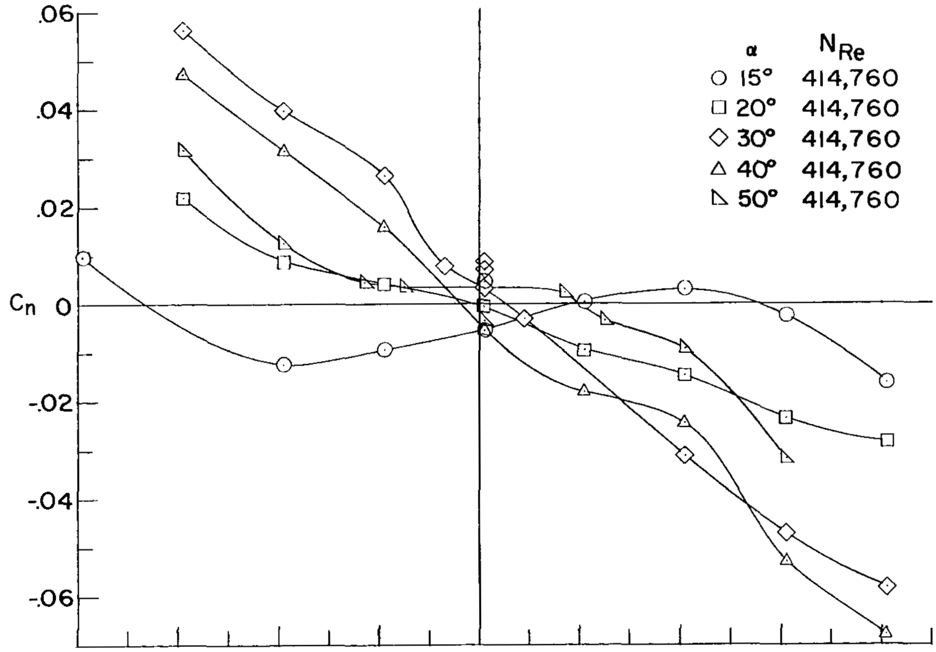
Figure 7.- Strip photograph of model 1 launched with canard 6 installed 0.18 inch below reference line.

[redacted]

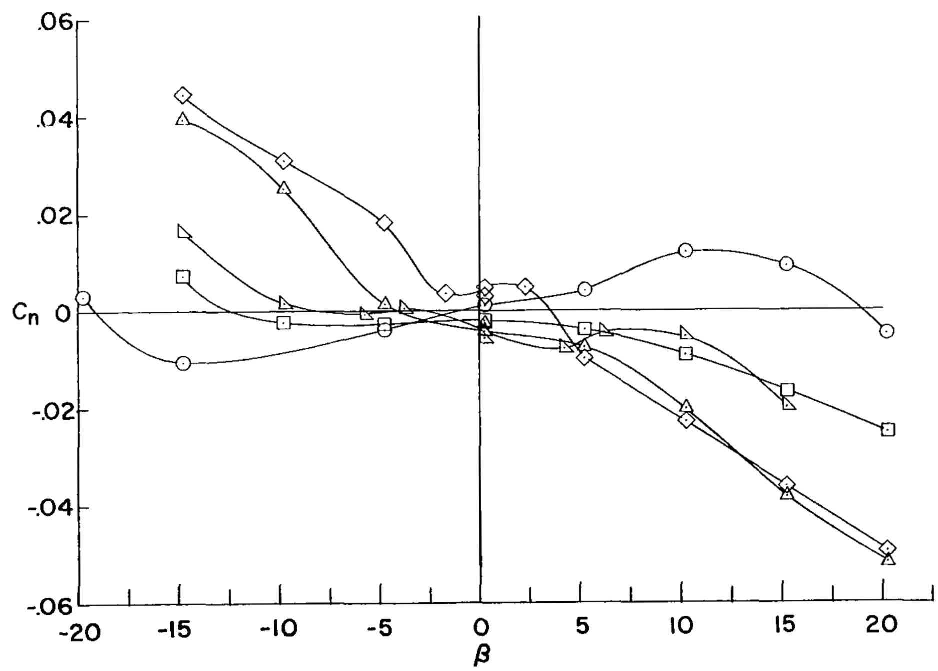


L-92429

Figure 7.- Concluded.

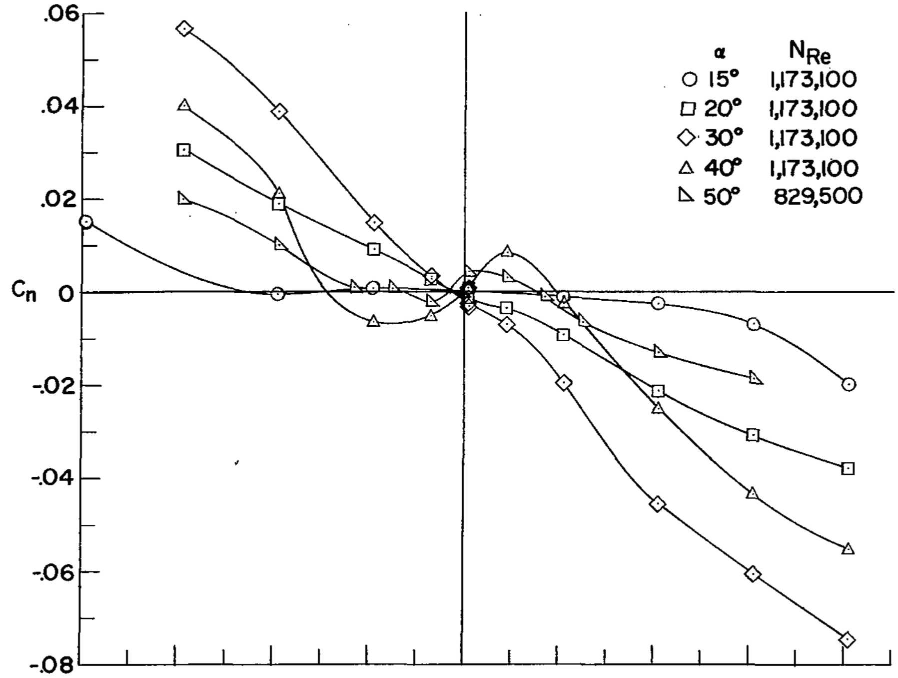


(a) Canards off.

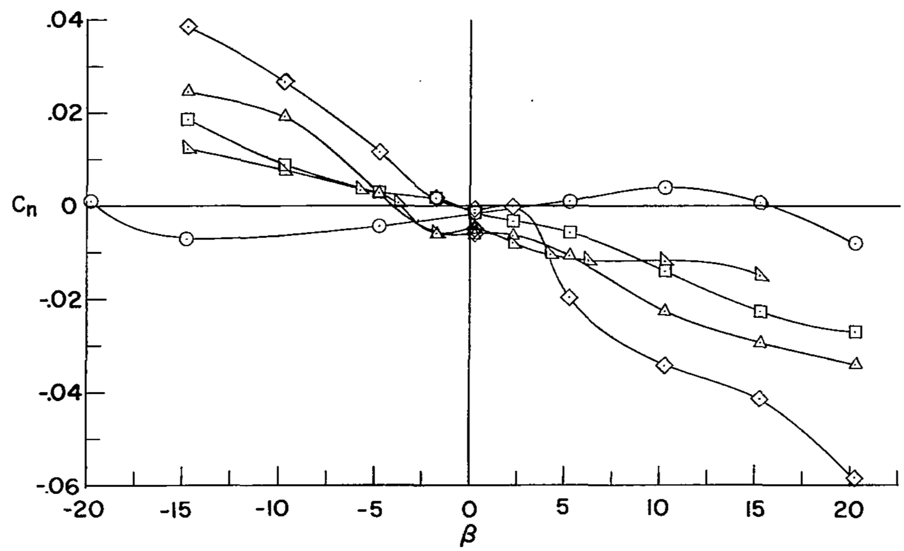


(b) Canards on.

Figure 8.- Yawing moment plotted against sideslip. Canards on and off.

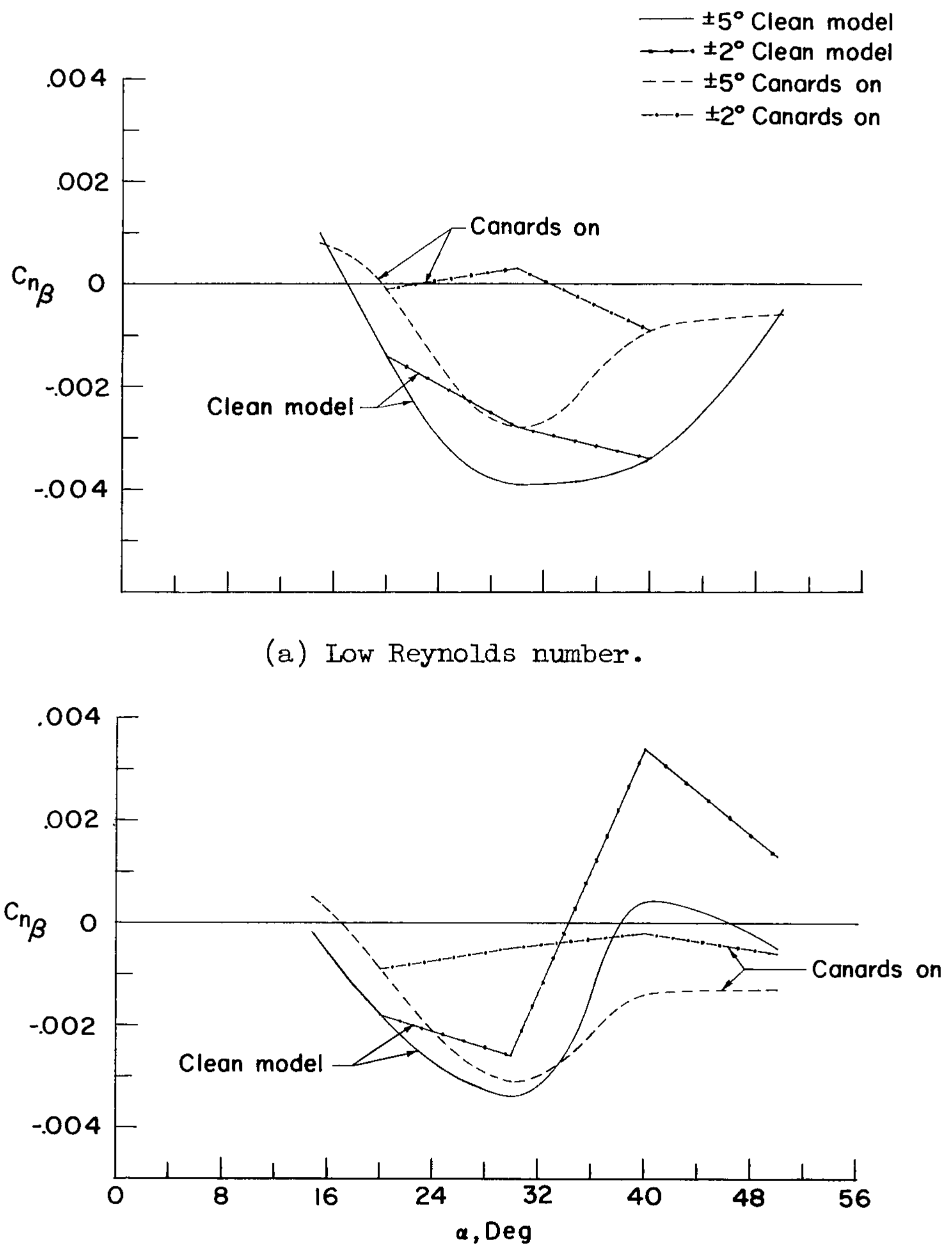


(a) Canards off.



(b) Canards on.

Figure 9.- Yawing moment plotted against sideslip. Canards on and off.



(a) Low Reynolds number.

(b) High Reynolds number.

Figure 10.- C_{n_β} plotted against α.

NACA - Langley Field, Va.